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Effects of a Food Waste-Based Soil Conditioner On Soil Properties and Plant Growth

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The objective of this study was to evaluate the effects of a soil conditioner, prepared from food wastes, on soil microbial activity, soil nutrient levels, and melon (*Cucumis melo reticulata*) growth and yield. Food waste, generated from a residence dining hall, was fermented with and without a microbial inoculant for 20 days. The resulting soil conditioners were incorporated into soil (Mexico silt loam) by tilling to a 15-cm depth using a rotary tiller. Melon seedlings were transplanted three weeks after soil amendment. Soil nutrient levels and microbial activity were monitored periodically during the growing season to detect effects of the soil conditioners on soils and plant growth. Fruit weight per plant was significantly ($P \leq 0.05$) increased with the microbially-inoculated soil conditioner compared to the control in both years, but was not different from the non-inoculated soil conditioner in 2000 or the fertilizer treatment in 2001. Soil conditioners produced from food wastes inoculated with selected microorganisms were as effective as a fertilizer in promoting soil microbial activity and melon growth. Long-term studies (> 2 yr) are needed to verify that enhancement of microbial activity and plant growth is due exclusively to EM-based soil conditioners.

Introduction

Recycling food wastes into value-added products such as soil conditioners can decrease disposal costs and recycle nutrients for maintaining and improving soil quality and crop growth (Martin and Gershuny 1992; Zibilske 1998). More than 26 million tons of food wastes were generated in 2001, accounting for about 16% of the municipal solid waste stream in the United States (Miller 2004). Disposal of organic materials including food wastes is becoming more constrained due to decreased landfill areas and bans on incineration (Risse and Faucette 2000). Therefore, composting has become an attractive means for diverting food wastes from landfills and reducing waste management costs. Composting food wastes has not gained wide acceptance due to odor and pest problems associated with conventional waste collection and processing methods (Donahue *et al*. 1998). Sealed containers ("in-vessel composting systems") circumvent odor and pest problems and facilitate decomposition by fermentation, yielding a product that can be applied as a soil conditioner (Martin and Gershuny 1992).

Microbial inoculants improve plant production by reducing plant stress and increasing nutrient availability (Kinnersley 1993). One such microbial inoculant, available as 'Effective Microorganisms' (EM), consists of a suspension of ≥80 naturally-occurring microorganisms including phosphorus-solubilizing bacteria, lactic acid bacteria, yeasts, cellulolytic bacteria, and actinomycetes, which are documented to improve soil quality and crop growth (Higa 1993; Wididana and Higa 1995). Most of the microorganisms in EM cultures are heterotrophic (require organic substrates as carbon and nitrogen sources), therefore, EM has been most effective when combined with organic carriers and applied to soils and crops (Yamada and Xu 2000). Addition of EM to organic materials including food wastes contained within in-vessel systems enhances fermentation and the composting process (Higa 1993). Various soil conditioners including composted materials may improve plant growth by improving soil nutrient availability and soil physical properties (Kinnersley 1993; Zibilske 1998; Six *et al.* 2000; Havlin *et al.* 1999). However, there is little information on the effects of composted food waste, produced with a microbial inoculant, on soil properties and plant growth. The objective of this study was to evaluate the effects of a food waste soil conditioner, fermented with and without a microbial inoculant, on soil nutrient levels, soil microbial activity, and plant growth and yield of field-grown melons.

Materials and Methods

Food Waste

Food, drink, and paper wastes were collected from a student-dining hall at the University of Mis-

souri, Columbia. Wastes were shredded into 3- to 10-cm pieces to form a pulp-like slurry and centrifuged to remove excess fluid using waste-processing equipment installed at the dining hall. Wastes prepared in this manner were used for composting.

Microbial Inoculum Preparation

EM (Sustainable Community Development, Columbia, Missouri) concentrate (150 ml) was mixed with 150 ml dark molasses to initiate active growth of the microorganisms; this mixture was diluted in 15 liters of tap water warmed to 35-45°C. The suspension was evenly distributed in 45 kg of soft wheat bran by constantly mixing the bran by hand on a cement slab. The resulting bran-suspension mixture had no clumps and 20% moisture content. This mixture was packed firmly in clean airtight 19-L plastic containers for 14 days. After incubation the bran mixture was removed from the containers, air-dried, and served as inoculum for composting the food wastes.

Production of Soil Conditioners

The prepared wastes were homogenized by manually turning over the material with a shovel. The uniform waste material was then divided into equal portions; one portion was mixed with uninoculated bran and the other was mixed with the EM-bran inoculum at a ratio of 1:5.3 (v:v). Each waste treatment was dispensed into separate enclosed containers, which served as anaerobic fermentors for in-vessel composting. The enclosed containers were built from opaque, plastic, 190-L barrels open at the top; a platform covered with 1-cm^2 galvanized wire mesh was placed in the bottom to allow liquid to drain from the wastes. Tops of the containers were sealed with plastic sheeting (4-mil) held in place by a rubber gasket secured with plastic lids. Temperatures inside during fermentation ranged from 20 to 28°C. Liquid from the enclosed containers was drained daily during the first week and every other day thereafter. At the end of fermentation (20 days), the composted wastes were considered "soil conditioners" and available for application to the field.

Field Procedures

Experimental plots were established on a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) previously under weedy vegetation and with an unknown history of tillage and fertilization practices. Soil treatments included: no fertilizer (No Fert); fertilizer [Fert; 13-13-13 (N-P-K)] at 520 kg·ha^{-1}; EM soil conditioner applied at 12,500 kg (dry weight)·ha^{-1}; and non-EM soil conditioner applied at 12,500 kg(dry weight)·ha^{-1}. Each treatment was arranged in a randomized complete block design with four replicate blocks established in the field. Soil conditioners were applied 3 weeks before planting. All treatments were incorporated into soil by tilling to a 15-cm depth using a rotary tiller. Muskmelon (*Cucumis melo reticulata* cv 'Ambrosia') transplants were planted into plots on June 5, 2000, and May 17, 2001. Each plot consisted of 3 rows, 5 plants each, planted in an east-west direction. Plants were spaced 90 cm apart in the row with 1.5 m between rows. Data were collected from the center row of each plot. Outer rows were established to minimize edge effects and to monitor insects and diseases. Treatments were re-applied to the same plots in the second year of the study.

Soil Conditioner and Soil Analyses

Random samples from each of four production batches of soil conditioners were collected immediately prior to soil application and air-dried for chemical analysis. Soil samples were collected before treatment application and at transplanting. Four soil samples from each treatment row were taken to a depth of 18 cm and mixed to yield a composite sample for analysis. All analyses for both soil conditioners and soils were performed by the Soil Testing Laboratory at the University of Missouri, Columbia, based on standard procedures (Dahnke 1988). For the soil conditioners, chemical analyses were determined as follows: pH by the saturated paste method; total nitrogen by the standard Kjeldahl method; carbon by loss on ignition; and phosphorous, potassium, calcium, magnesium, zinc, iron, manganese and copper contents by strong acid digestion. For soils, chemical analyses were determined as follows: pH by the dilute calcium chloride method; organic matter content by loss on ignition nitrate by cadmium reduction; ammonium by the phenolate method; phosphorous by the Bray I method; potassium, calcium, magnesium by ammonium acetate exchange; and sodium by a saturated paste method.

Soil microbial activity, expressed as triphenyltetrazolium chloride (TTC)-dehyrogenase activity, was used to estimate respiration of viable microorganisms (Casida 1977). Soil (6 g) was incubated in 1.0 ml of 3% TTC and 3.0 ml of 0.2M $CaCO_3$ for 24 h at 37°C. Assays were conducted with three replicates containing TTC and one control with 8 ml deionized water. The reactions were terminated by addition of 50 ml methanol and extracted 30 min on a reciprocal shaker. The reaction mixture was filtered and the con-

centration of 2,3,4-triphenyl-tetrazolium formazan (product) was determined spectrophotometrically at 485 nm.

Harvesting Procedures

Plant samples and mature fruit were collected during a single harvest 79 days after transplanting in 2000 and 90 days after transplanting in 2001. All plants in each plot were severed at soil level and separated into vegetative (stems plus leaves) and fruit components. Stems plus leaves were placed into paper bags and dried using a forage dryer for 5 to 7 days at 45°C, then weighed to determine above-ground dry weight per plant. Number and fresh weight of fruit per plant were determined for each plot.

Statistical Analysis

Data were subjected to an analysis of variance and where the F-test was significant, Fisher's protected least significant difference (LSD) test at P=0.05 was used for mean separation.

Results and Discussion

Soil Conditioner Properties

The in-vessel composting system used in our study effectively reduced noticeable odors during the fermentation period. Moisture content of the food waste was also reduced based on the removal of 15 – 20 L leachate from each enclosed container during fermentation. Temperatures of the composting food waste during fermentation ranged from 20°C to 28°C. After one week of fermentation, the composting material was not recognizable as food waste and appeared as indistinguishable pulp. EM-inoculation resulted in a sweet, fermented smell inside the enclosed container at one week of fermentation with white mycelial-like growth on the surface of the pulp. Non-EM inoculated pulp produced a putrefied, rancid odor inside the vessels after the first week of fermentation and had less mycelial growth than the inoculated pulp. However, the odor dissipated by the end of the 20-d fermentation period. Although the mechanisms are not clearly understood, EM inoculation of organic materials improves the quality of composts partly due to lactic acid synthesis and propagation of *Lactobacillus* that provides consistent fermentation (Kostov *et al.* 1991; Yamada and Xu 2000).

Total nitrogen, potassium, phosphorous, calcium, magnesium, zinc, iron, copper, total carbon and carbon:nitrogen ratios (C:N) of the soil conditioners were comparable regardless of EM inoculant application (Table 1). The narrow C:N ratio (10 to 12:1) of the food waste soil conditioners was favorable for plant nutrition because nitrogen immobilization by soil microorganisms was unlikely (Martin and Gershuny 1992). Total nitrogen, phosphorous, potassium, calcium, magnesium, iron, molybdenum, copper, carbon, and C:N ratio were less variable among samples of EM soil conditioner compared to the non-EM soil conditioner. Based on these properties, a consistent microbial community likely developed with EM inocula that contributed to stable chemical properties of the organic material during fermentation (Kostov *et al.* 1991; Yamada and Xu 2000).

TABLE 1.
Nutrient levels and carbon:nitrogen ratios for non-em and em soil conditioners after 20 days incubation*

Variable	Non-EM	EM
PH	5.83 (0.57)	5.49 (1.01)
Total N %	4.07 (0.68)	3.71 (0.60)
Total P %	0.75 (0.34)	0.72 (0.24)
Total K %	0.56 (0.57)	0.65 (0.38)
Total Ca %	1.20 (1.16)	0.60 (0.23)
Total Mg %	0.23 (0.15)	0.23 (0.09)
Total Zn ppm	174 (235)	201 (302)
Total Fe ppm	183 (54)	140 (43)
Total Mn ppm	59 (49)	60 (28)
Total Cu ppm	7 (9)	7 (6)
Total C %	40 (4)	43 (2)
C:N Ratio	10.11 (1.87)	12.00 (1.49)

* Numbers in parenthesis are standard deviation. Means represent four random samples taken from four independent production times of the soil conditioners.

Soil Properties

Soil organic matter increased in plots treated with EM and non-EM soil conditioners when sampled in June 2000 and April 2001, compared to Fert and No Fert plots (Table 2). Soil conditioners likely contributed to increases in soil organic matter (Havlin *et al.* 1999; Martin and Gershuny 1992; Zibilske 1998), however, soil organic matter content was less in 2001 compared to 2000 regardless of treatment. Except for P and N, soil nutrient levels were not greatly affected due to treatment in either growing season. Increases in available P, nitrate, and ammonium in amended soils suggest that the soil conditioners stimulated solubilization and mineralization of P, and mineralization of N by soil microbial communities. Additional tillage after the 2000 growing season might have decreased organic matter and mineralization (Wagner and Wolf 1998).

TABLE 2.
Soil nutrient levels in plots receiving soil conditioners, 2000 and 2001

Sampling Time	Treatments	pH	Organic Matter %	N.A.[1] meq/100g	P ($kg \cdot ha^{-1}$)	Ca ($kg \cdot ha^{-1}$)	Mg ($kg \cdot ha^{-1}$)	K ($kg \cdot ha^{-1}$)	NO_3 ppm	NH_4 ppm
Pre-	No fert	6.9 a	3.2 a	0.4 a	84 a	5276 a	488 a	454 b	---	---
Treatment	Fert	6.9 a	3.2 a	0.3 a	94 a	5710 a	566 a	504 ab	---	---
May 15,	EM S.C.	7.0 a	3.2 a	0.5 a	101 a	5580 a	494 a	584 a	---	---
2000	Non-EM S.C.[3]	6.9 a	3.2 a	0.3 a	96 a	5718 a	547 a	526 ab	---	---
Post-	No fert	7.0 a	3.2 b	0.2 a	77 b	3998 a	338 a	300 b	4.6 b	0.9 b
Treatment	Fert	6.8 a	3.2 b	0.3 a	95 ab	4041 a	362 a	370 a	4.0 b	1.4 ab
June 5,	EM S.C.	6.8 a	3.4 a	0.3 a	101 a	4104 a	349 a	316 b	12.4 a	2.2 a
2000	Non-EM S.C.	6.8 a	3.4 a	0.4 a	112 a	4150 a	356 a	372 a	8.3 ab	1.8 a
Pre-	No fert	6.9 a	2.2 b	0.4 b	99 c	7665 a	775 a	423 b	2.2 b	11.0 a
Treatment	Fert	6.8 a	2.3 b	0.6ab	107 bc	8190 a	905 a	520 a	2.3 b	9.9 a
April 19,	EM S.C.	6.8 a	2.6 a	0.8 a	130 ab	7825 a	819 a	441 b	3.9 ab	10.8 a
2001	Non-EM S.C.	6.8 a	2.6 a	0.7ab	131 a	7793 a	810 a	454 ab	4.9 a	13.6 a
Post-	No fert	6.8 a	2.4 a	0.7 a	94 b	7566 a	804 a	418b	5.6 c	10.1 b
Treatment	Fert	6.8 a	2.4 a	0.9 a	104 b	7823 a	898 a	478 ab	6.4 c	10.1 b
May 17,	EM S.C.	6.8 a	2.4 a	0.7 a	110 b	7437 a	810 a	468 ab	15.8 b	10.6 b
2001	Non-EM S.C.	6.8 a	2.4 a	0.7 a	130 a	7642 a	844 a	513 a	34.5 a	17.7 a

Means within a column for a sample date followed by the same letter are not significantly different based on Fisher's protected LSD (P=0.05); [1]N.A. – Neutralizable Acidity; [2]EM S.C. – EM-inoculated Soil Conditioner; [3]S.C. – Soil Conditioner

TABLE 3
Soil dehydrogenase activity (mg TPF[1]$\cdot g^{-1}$ dry soil)

	Pretreatment		Transplanting		Harvest	
Treatments	2000	2001	2000	2001	2000	2001
No fert	1820 a	550 b	2000 cb	720 a	2430 a	120 ab
Fert	1650 a	570 ab	1860 c	670 a	2000 a	100 b
EM Soil conditioner	1910 a	710 ab	2850 a	760 a	2680 a	150 a
Non-EM Soil conditioner	1740 a	780 a	2690 ab	660 a	2400 a	130 a

[1] TPF-triphenyl formazan; Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD (P=0.05).

Soil dehydrogenase activity was similar across all plots at the initial 2000 sampling date (Table 3), suggesting that microbial activity was consistent throughout the field before treatment. At 16 days after treatment (June 11, 2000), dehydrogenase activity in soil amended with EM soil conditioner was significantly greater than the No Fert and Fert treatments but was not different from soil amended with non-EM soil conditioner. Soil conditioners provide available nutrients to soil organisms and promote microbial activity involved in soil aggregation and nutrient cycling (Lynch and Elliott 1997). In our study, increases in enzyme activity were transient because by 82 days after soil application, dehydrogenase activity among treatments did not differ significantly. Previous studies have shown that long-term application of organic materials composted with EM inocula improved physical, chemical, and biological properties of soils (Higa and Parr 1994, Xu 2000, Yamada and Xu 2000). Our study was conducted over a two-year period; annual applications of EM-soil conditioner during additional growing seasons may improve soil properties at our field site that could be consistently detected over time.

Melon plant dry weight, numbers of fruit per plant, and average fruit weight per plant followed similar trends over both growing seasons with higher yields associated with both soil conditioners relative to No Fert and Fert treatments (Table 4). Aboveground dry weight per plant did not differ between treatments in 2000, but was highest for EM-soil conditioner and Fert in 2001. Number of fruit per plant

TABLE 4
Yield data for 2000 and 2001

Treatments	Above Ground Dry Weight Per Plant		Number of Fruit Per Plant		Fruit Weight Per Plant (kg)	
	2000	2001	2000	2001	2000	2001
No fert	0.39 a	0.11 b	2.9 b	1.1 b	3.9 b	0.9 b
Fert	0.43 a	0.13 ab	3.1 b	1.2 b	4.5 b	1.2 ab
EM Soil conditioner	0.57 a	0.18 a	5.1 a	1.8 a	7.5 a	2.0 a
Non-EM Soil conditioner	0.45 a	0.12 b	4.0 ab	0.9 b	6.5 a	0.9 b

Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD (P=0.05).

was significantly increased with EM soil conditioner compared to Fert and No Fert in both years, but was not different from non-EM soil conditioner in 2000. Fruit weight per plant was also significantly increased with EM soil conditioner compared to No Fert in both years, but was not different from non-EM soil conditioner in 2000 or the Fert treatment in 2001.

Melon yield components (fruit numbers and fruit weight) with both soil conditioners were higher or comparable to the Fert treatment suggesting that these organic amendments can be used successfully for providing adequate nutrition for melon production. Soil properties improved by soil conditioners promote growth and activity of plant root systems, which is ultimately reflected in improved harvestable yields (Lynch and Elliott 1997; Xu 2000). Long-term use of EM-inoculated soil conditioners further promotes plant growth through the buildup of beneficial microbial communities that produce plant-growth-promoting substances including auxins, gibberellins, and kinetins (Higa and Parr 1994; Xu 2000). We observed beneficial effects of soil conditioners on soil enzyme activity and plant growth, however, additional growing seasons are needed to verify any growth-promotive effects due exclusively to use of EM for producing a soil conditioner from food waste. Subsequent studies have shown that soils amended with organic materials similar to the food waste conditioners with and without EM treatment developed higher levels of soil enzyme activities, soil organic matter content, and water-stable soil aggregates relative to soils not receiving organic amendments (data not presented).

Conclusions

Microorganisms in EM were effective in production of soil conditioners from food waste with a fermentation process that alleviated formation of offensive odors (Kostov *et al.* 1991). For commercial composting operations, preparation of EM inoculant with bran and subsequent inoculation of food wastes could be scaled up by using commercially-available compost mixers. Also, compost turning equipment might be used to form windrows of the inoculated food waste of sufficient size to provide anaerobic conditions within the windrow for fermentation. This would eliminate the necessity of using in-vessel fermentors. Further study is needed for evaluation of food waste soil conditioners using different soils, application methods, and crops. Evaluation of long-term use (> two growing seasons) might aid in determining relationships between soil nutrient levels and plant growth and production, and account for variation due to weather patterns. Long- term evaluation of soil quality parameters (i.e., soil enzymes) and plant growth under field conditions is needed to verify the beneficial effects of soil conditioners prepared with EM.

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